



Challenges and Opportunities for Orbital Debris Environment Remediation

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**2nd European Workshop on Active Debris Removal
CNES HQ, Paris, France, 18-19 June 2012**



The “Next Step” from my Presentation in 2010



The Challenges Ahead – a Personal Perspective

- **Reach a consensus on the instability problem of the LEO debris environment**
- **Determine if there is a need to use ADR for environment remediation**
 - Define “what is acceptable”
 - Establish a timeframe to move forward
- **Commit the necessary resources to support the development of low-cost and viable removal technologies**
- **Address the policy, coordination, ownership, legal, liability, and other issues at the national and international levels**



Instability of the LEO OD Environment

- The LEO environment instability issue is under investigation by the Inter-Agency Space Debris Coordination Committee (IADC) members
- An official “Stability of the Future LEO Environment” comparison study was initiated in 2009
 - Six participating members: NASA (lead), ASI, ESA, ISRO, JAXA, and UKSA
 - Results from the six different models are consistent with one another, *i.e.*, even with a good implementation of the commonly-adopted mitigation measures, the LEO debris population is expected to increase in the next 200 years
 - A white paper will be issued in the coming year

Inter-Agency Space Debris Coordination Committee





Options for LEO Environment Remediation

– The Big / Complete Picture



Define the Problems

- **The problem: LEO debris population will continue to increase even with a good implementation of the commonly-adopted mitigation measures**
 - The root-cause of the increase is catastrophic collisions involving large/massive intact objects (R/Bs and S/C)
 - The major mission-ending risks for most operational S/C, however, come from impacts with debris just above the threshold of the protection shields (~5-mm to 1-cm)
- **A solution-driven approach is to seek**
 - Concepts for removal of massive intacts with high $P_{\text{collision}}$
 - Concepts capable of preventing collisions involving intacts
 - Concepts for removal of 5-mm to 1-cm debris

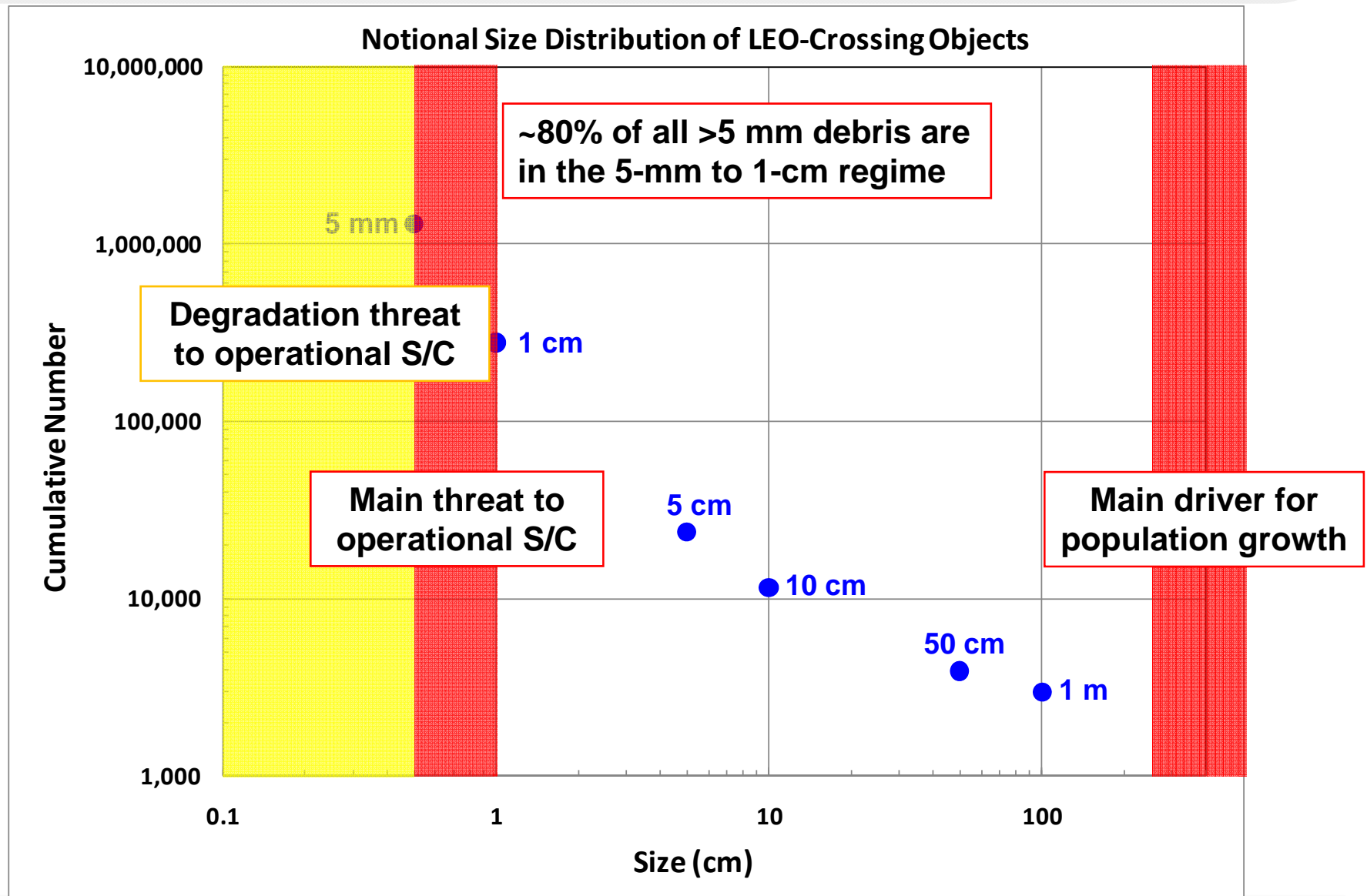


The Three Options

- **Removal of massive intact objects with high collision probabilities to address the root cause of the future debris population growth problem**
- **Removal of 5-mm to 1-cm debris to mitigate the main threat for operational spacecraft**
- **Prevention of major debris-generating collisions involving massive intact objects as a potential short-term solution**



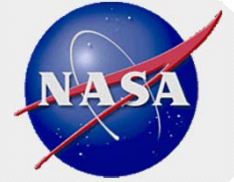
Targets for Removal





Focused Active Debris Removal

- **To address the root cause of the population growth (for large and small debris)**
 - **Target objects with the highest [$M \times P_{\text{coll}}$]**
 - To maintain the future LEO debris population at a level similar to the current environment requires an ADR of ~5 massive intacts per year
- **To address the main threat to operational S/C**
 - **Target objects in the 5-mm to 1-cm regime**
 - The small debris environment is highly dynamic and will require a long-term operation to achieve the objective
- **Targeting anything else will NOT be the most effective means to remediate the environment nor to mitigate risks to operational S/C**

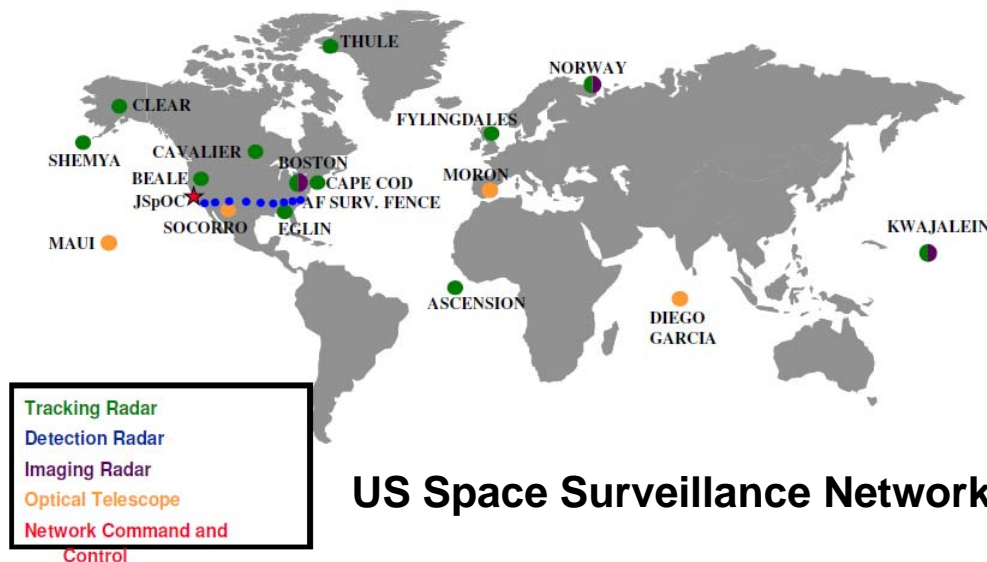


Challenges for LEO Environment Remediation



Collision Prevention

- **Prevention of major debris-generating collisions may be considered a potential short-term solution**
 - Since no mass is removed from the environment, this is only a temporary solution
 - For collision prevention to be an effective means to limit future debris growth, it has to be applied to most predicted conjunctions involving intact objects (including R/Bs and retired S/C)





Current Conjunction Warnings

- **U.S. DoD's Joint Space Operations Center (JSpOC) conducts conjunction assessments for all operational S/C in the environment**
 - A warning is issued for LEO S/C when (1) a miss distance is less than 1 km and (2) a radial miss distance is less than 200 m during the forecast period of 72 hours
- **On average JSpOC issues ~30 conjunction warnings on a daily basis, and more than 100 collision avoidance maneuvers were carried out by satellite operators in 2010**
 - These numbers are for LEO-to-GEO, most are in LEO
 - If JSpOC were to expand its conjunction coverage to LEO R/Bs and retired S/C, approximately 20,000 to 36,000 conjunction warnings involving LEO intact objects per year are expected



Challenges for Collision Prevention

- **To allow for actionable collision prevention operations**
 - JSpOC must expand its conjunction assessments to include R/Bs and retired S/C
 - Dramatic improvements to debris tracking and conjunction assessment accuracy are needed
- **Collision prevention operations must be applied to most, if not all, conjunction warnings**
- **Targets are limited in number, but ~2/3 are large and massive R/Bs or S/C (up to 9 metric tons dry mass)**
- **Concepts proposed by various groups: ballistic intercept, frozen mist, laser-nudging, *etc.***



Challenges for Small Debris Removal

- **Targets are small**
 - Approximately 5-mm to 1-cm
- **Targets are not tracked by SSN**
- **Targets are numerous (>500,000)**
 - For any meaningful risk reduction, removal of a significant number of targets is needed
- **Targets are highly dynamic**
 - Long-term operations are needed
- **Concepts proposed by various groups: large-area collectors, laser removal, tungsten dust, etc.**



Challenges for Large Debris Removal

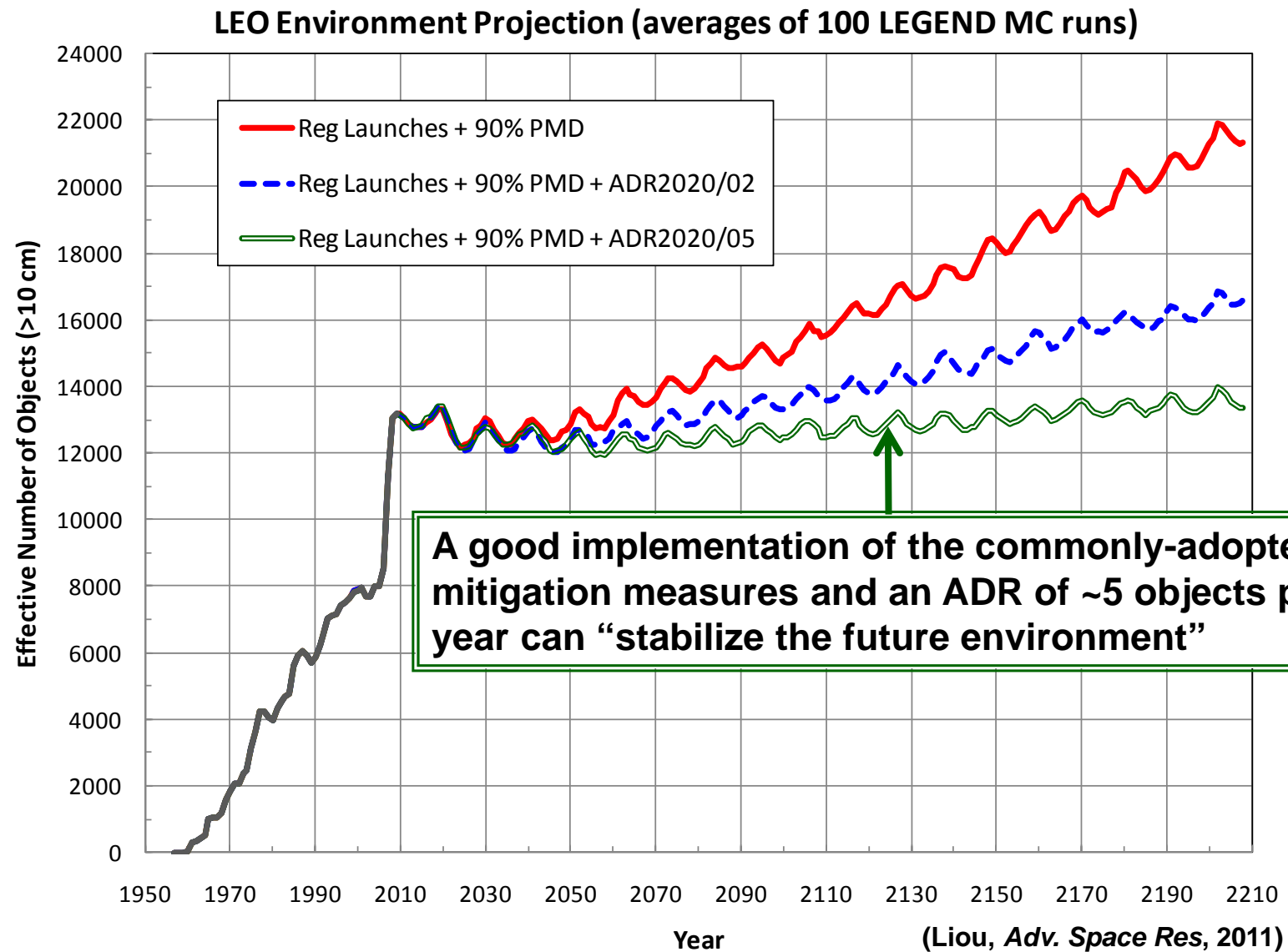
- **Targets are limited in number, but large and massive (up to ~9 tons); tumble motion varies**
- **To stabilize the future LEO environment, removal of ~five high [$M \times P_{\text{coll}}$] objects per year is needed**
- **Do no harm – Many intacts have leftover propellants, batteries, pressurized systems**
- **Controlled reentry may be necessary for many massive intacts**
- **Concepts proposed by various groups: Drag-enhancement devices, electrodynamic tethers, grapple-and-tug, laser removal, *etc.***



Effectiveness of Large Debris Removal

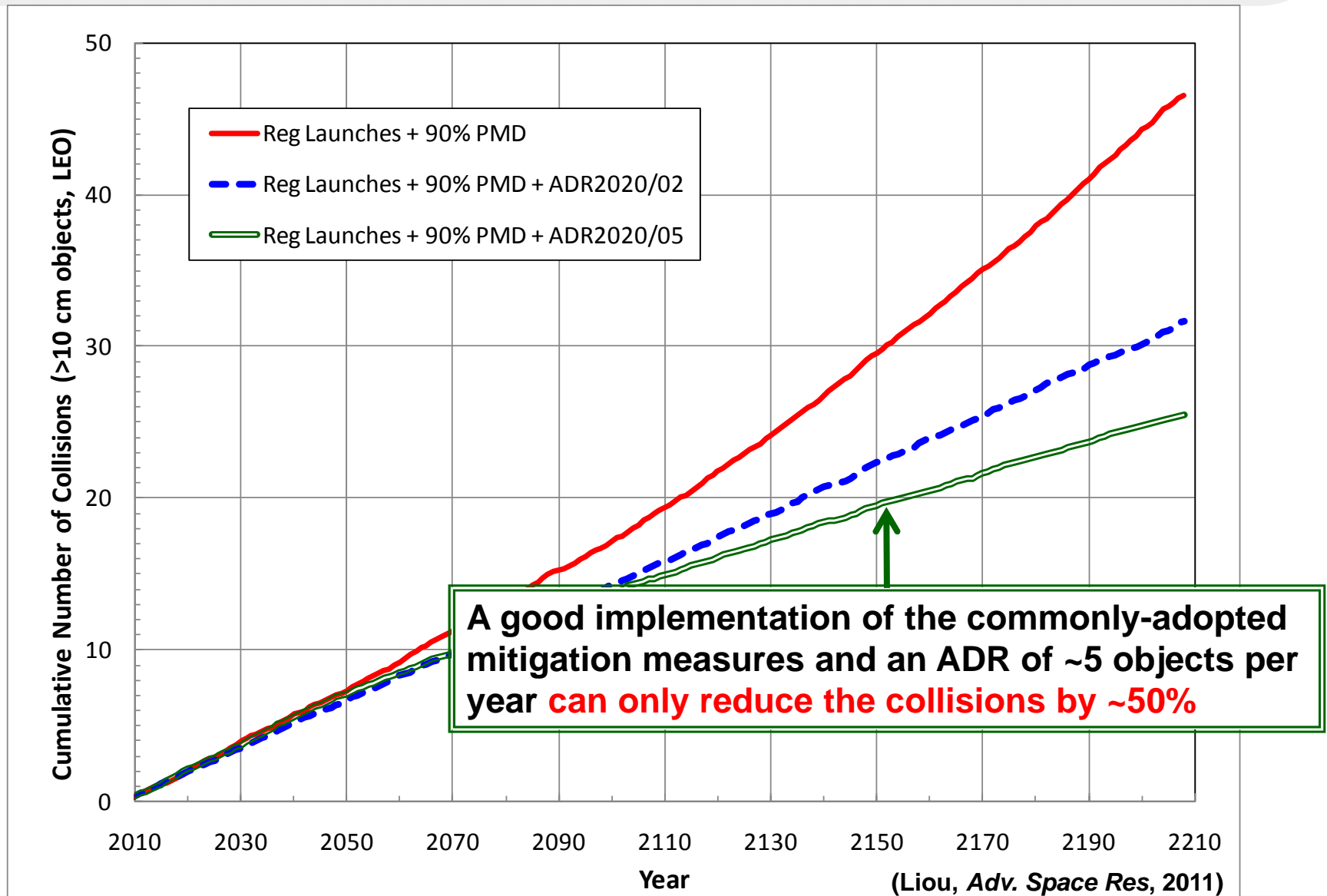


Controlling Debris Growth with ADR





Projected Collision Activities in LEO





About the “Five Objects Per Year”

- **The “removing 5 objects per year can stabilize the LEO environment” conclusion is somewhat notional. It is intended to serve as a benchmark for ADR planning.**
- **Assumptions in the LEGEND ADR simulations**
 - Nominal launches during the projection period
 - 90% compliance of the commonly-adopted mitigation measures
 - ADR operations starts in 2020
 - Target selection is based on each object’s mass and P_{coll}
 - No operational constraints on target selection
 - Immediate removal of objects from the environment
 - Average solar activity cycle



About Future Environment Projection

- **Options for future projection**
 - Examine extreme cases to bound the outcome
 - Make reasonable assumptions and draw conclusions from the nominal/average results
- **Options to present Monte Carlo simulation results**
 - Averages
 - Averages with σ 's
 - Tabular Format
 - Scatter Plots
 - Distributions
 - Averages and extremes
 - Individual projections
 - Others



Examples

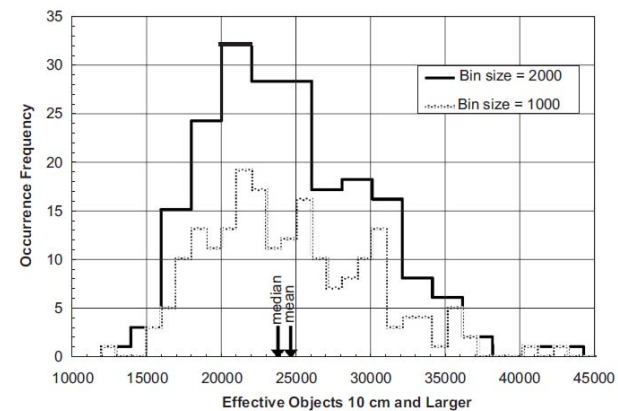
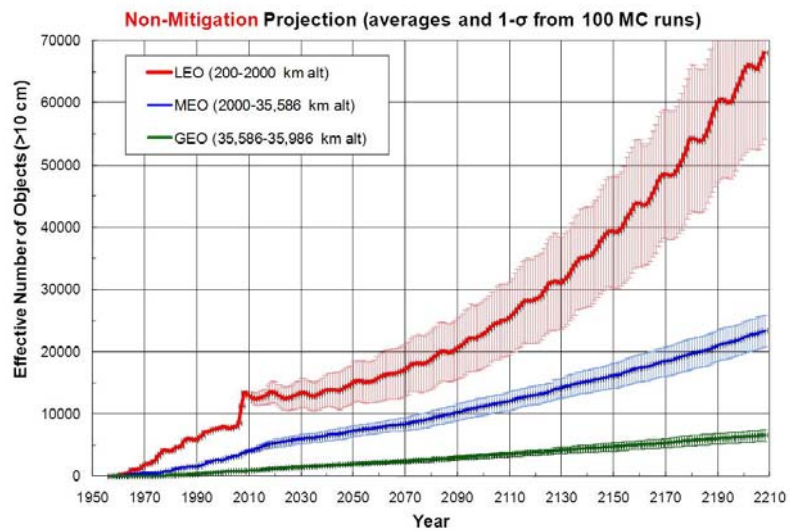
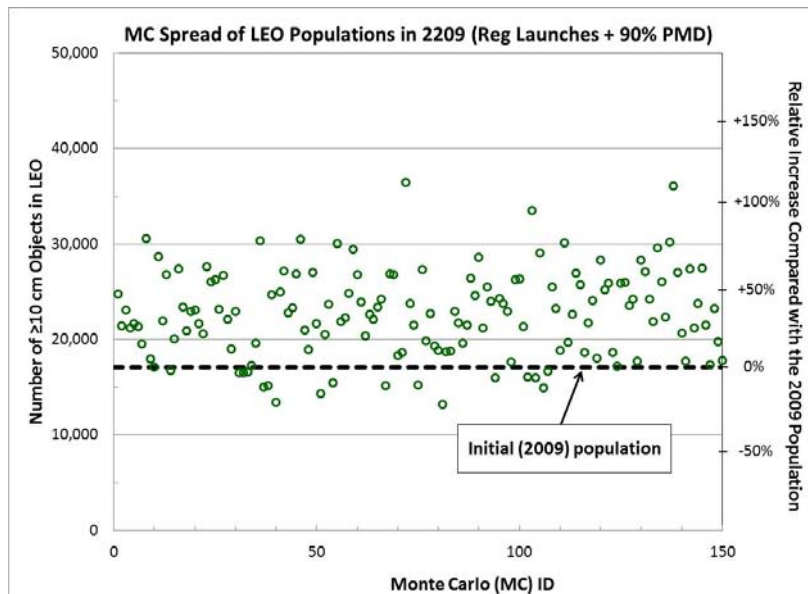


Fig. 3. Distribution of the projected LEO debris populations (≥ 10 cm) in 2104 from 200 MC simulations. Two different bin sizes are used to make the two histograms. Neither one resembles a Gaussian distribution. The mean and median of the 200 samples are indicated by the two down arrows. The bootstrap estimated 90% confidence interval of the mean is between 23,900 and 25,100.



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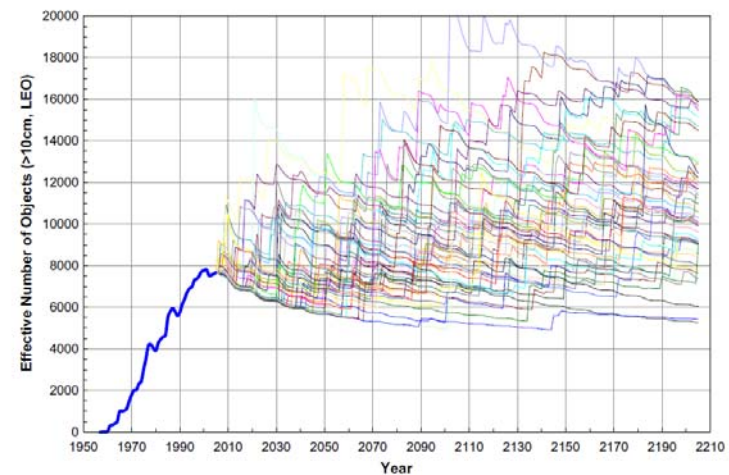


Fig. 3. Individual population growths (effective number of LEO objects 10 cm and larger) from the first 50 MC simulations. The sudden upward jumps are caused by breakups associated with each individual simulation.



What Does the ADR Simulation Mean?

- **Based on a set of reasonable assumptions, the removal of about 5 large/massive intact objects on a yearly basis is needed to stabilize the future orbital debris environment in LEO**
 - Collisions will continue to occur at a rate of approximately once every 9 years
- **The simulation results are intended to serve as a top-level guidance for future ADR planning**
- **In reality, the assessments of the environment and the needs for ADR will have to be evaluated on a regular basis**



The Challenges Ahead – a Personal Perspective

- **Determine if there is a need to use ADR for environment remediation**
 - Define “what is acceptable”
 - Establish a timeframe to move forward
- **Commit the necessary resources to support the development of low-cost and viable removal technologies**
 - Cost of a single target removal $\times 5 \times N$ years = ?
- **Address the policy, coordination, ownership, legal, liability, and other issues at the national and international levels**



Opportunities

- **Remediate the orbital debris environment after more than 50 years of human space activities**
- **Develop new technologies applicable to other space missions**
- **Provide a framework for international cooperation, collaboration, and contributions**



Backup Charts

- ADR Activities at the NASA Orbital Debris Program Office**

NASA Strategic Roadmap for Orbital Debris Environment Remediation



- **The ODPO leads a special study funded by the NASA HQ Office of the Chief Technologist (OCT)**
 - The panel consists of representatives from academia, DoD, industry, and five NASA Centers
- **Activities**
 - Phase I: Identify options for environment remediation, conduct top-level, qualitative assessments of a wide range of concepts, and identify the most feasible ones for Phase II
 - Phase II: Conduct detailed end-to-end mission analyses of the selected concepts, perform trade studies, identify TRLs and gaps of the applicable technologies, establish forward paths to advance the technologies, and then use the results to develop a strategic roadmap to guide NASA technology development in a focused, well-educated, and cost-effective manner

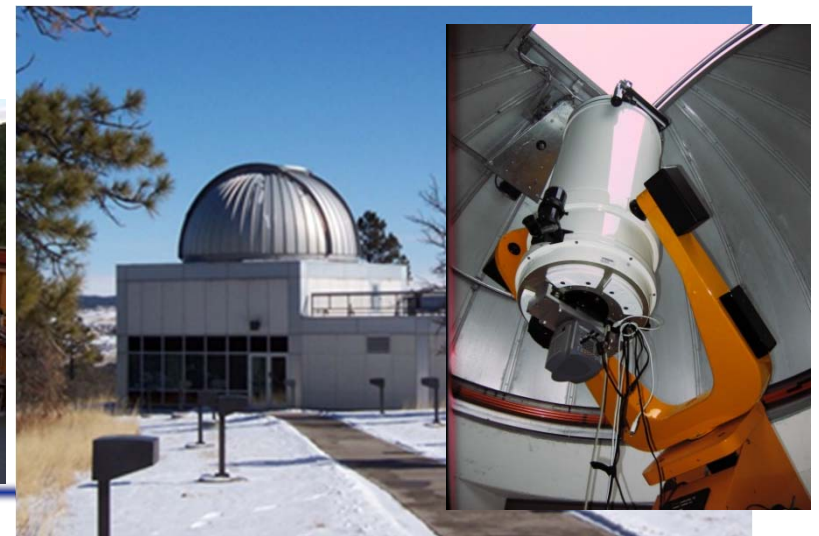


Rocket Body Light Curve Observations

- **The ODPO initiated two optical campaigns to collect light curve data of potential ADR targets**
 - A 3-month contract with the AF Academy led to the light curve data acquisition of 123 upper stages
 - An on-going effort using the New Mexico Skies' facility has collected light curve data of more than 130 upper stages
 - Laboratory emulation of the tumble motion of scaled upper stage mockups will help interpret the light curve data



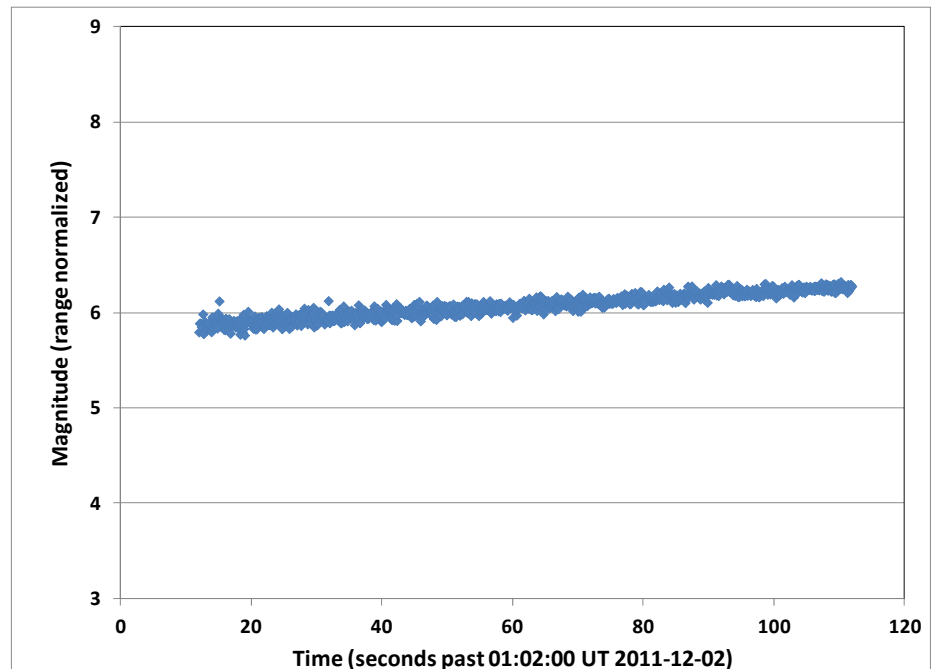
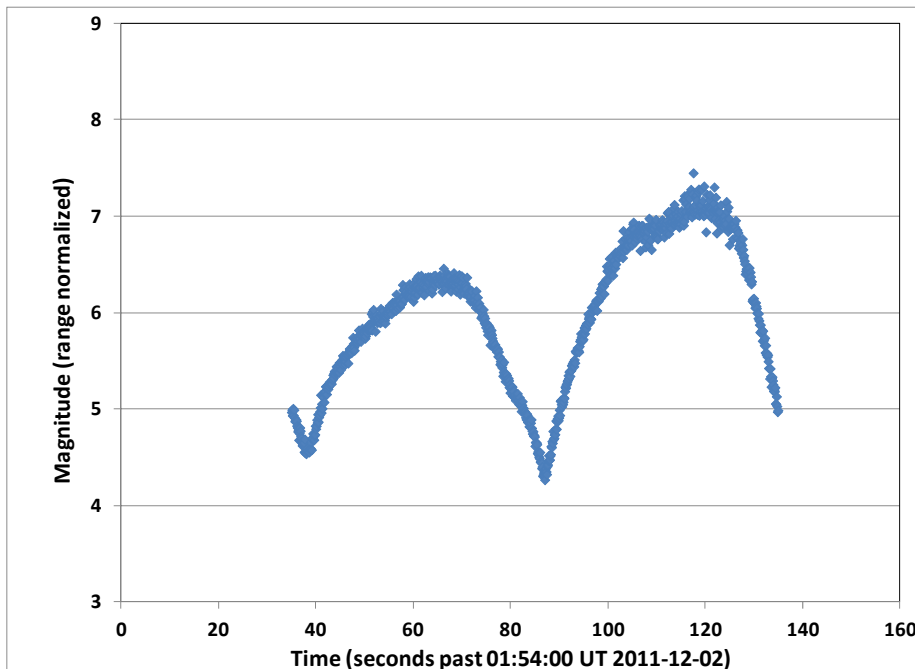
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Sample Light Curve Data

- **The observations conducted so far include objects with regular and irregular light curve patterns**
 - For those with regular light curves, some have rapid and large variations (left) while others are more stable (right)





Other Rocket Body Studies

- The ODPO is working with the AFRL to use the MCR C-band radar to collect data on potential ADR targets
- The ODPO has received stability/tumble data on dozens of upper stages from the SSN
- The ODPO is working with the Omsk State Technical University (OmSTU) and ISTC colleagues on reentry risk assessment of SL-8

